Michelson contrast for transparency perception in scenes with multiple luminances

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To perceive transparent media, such as stained glass, the visual system relies on a number of different cues [1], [2]. Singh and Anderson [3] proposed that contrast reduction may be a purely photometric cue to some types of transparency, where the contrast was Michelson contrast, $C = {}^{(L_{max}-L_{min})}/_{(L_{max}+L_{min})}$, and L_{max}, L_{min} were the minimum and maximum luminances. However, Singh and Anderson's stimuli were sinusoids and binarized noise, which are sufficiently characterized by L_{max},L_{min}.

Here, we consider how their findings would generalize to scenes with multiple gray levels (Fig. 1a), approaching the problem from a statistical perspective. We assume the following: (1) Each scene consists of a 3x3 checkerboard, where the reflectances are uniformly sampled from black (0%) to white (100%). (2) The transparent layer is thin and equally transmissive everywhere. (3) Lighting does not vary, thus luminance is reflectance times a constant. We assume that the constant is 1, meaning that luminance is $L \sim \mathcal{U}(0, 1)$.

First, we consider how to compute Michelson contrast for a checkerboard scene in plain view. A straightforward approach is to use L_{max}, L_{min} of each image, as with a sine wave. The distribution of contrasts, C_{sin} (Fig. 1b), is always positive since $L_{max} > L_{min}$. C_{sin} is also extremely skewed, high values occuring more than low values, meaning that luminances span a wide range within a sampled scene.

An alternative definition of Michelson contrast uses foreground and background luminances (L_f, L_b) instead of L_{max}, L_{min}. We let L_f be the luminance of the central square, and L_b be the mean luminance of the surrounding eight squares [4]. The resulting distribution, C_{fb} (Fig. 1c), is skewed with most of the density in -1 and +0.5 (Fig. 1c). This means that large, positive contrast occurs when L_b is near zero, which is unlikely because L_b is an average of non-negative numbers. Large, negative contrast occurs when L_f is near zero, and since L_f is sampled from $\mathcal{U}(0, 1)$, small values of L_f are common. Thus, the asymmetry is a consequence of luminances being uniformly distributed.

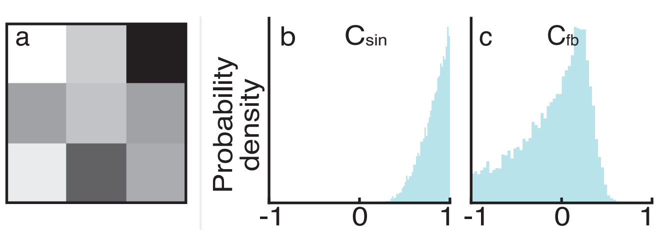

Fig. 1. a. Sample scene. b. C_{sin}, the distribution of contrasts using L_{max},L_{min}. c. b. C_{fb}, the distribution of contrasts using L_f,L_b.

Next, we consider contrast in scenes with transparencies. The plain view luminance (L_p) and the luminance of the transparent medium itself (τ) combine in a weighted sum, $L_t = \alpha L_p + (1 - \alpha)\tau$ [2]. The weight (α) is the physical transmittance of the transparency. For contrast under transparency, we use $L_{t_{max}}$,$L_{t_{min}}$ or L_{t_f},L_{t_b}. Algebraic manipulation shows that $C = {}^{(L_{p_{max}}-L_{p_{min}})}/_{(L_{p_{max}}+L_{p_{min}}+2\frac{(1-\alpha)}{\alpha}\tau)}$, or the equivalent with L_{p_f},L_{p_b}. Since τ is a luminance, $\tau \geq 0$, the presence of transparency can only lower contrast.

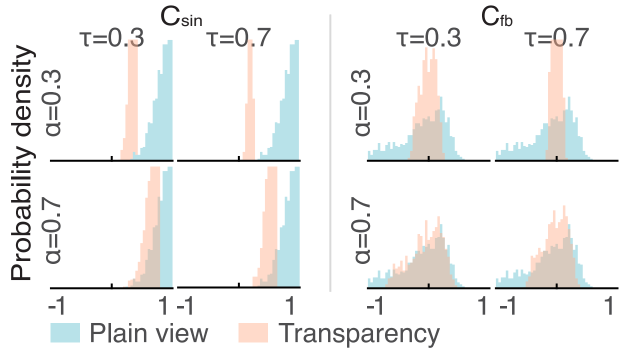

Fig. 2. Transparent layers scale the contrast distribution towards zero.

Simulations confirm this analysis, showing that transparent layers scale the contrast distribution towards zero (Fig. 2). Also, τ and α interact, providing a physics-based explanation to the empirical finding that a lighter transparency appears more opaque than a darker transparency with the same α [3].

Figure 2 shows that transparency perception may be modeled as classifying whether sampled luminances are more likely from the plain view or the transparency distributions. The classification accuracy is higher when the distributions are easier to distinguish, *i.e.*, the constrast reduction is severe. A caveat is that performance is the best when α is near zero, when the transparent layer is nearly opaque.

Distribution of Michelson contrasts can be complex in scenes with multiple luminances, especially since different luminance distributions will result in different contrast distributions. It remains to be seen which definition of contrast captures human perception the best. Framing transparency perception as a statistical problem makes it possible to build model observers that classify scenes as based only on luminance, and it would be interesting to quantify the divergence in human and model behavior when a scene has perceptually relevant geometric cues that do not change the photometric information.

References

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